Physics of the Cosmos (PCOS)
Strategic Technology Development Portfolio

October 2016

Current PCOS SAT Portfolio

Funding Source	Technology Development Title	Principal Investigator	Org	Start Year, Duration	Science Area	Tech Area
SAT2010	Directly-Deposited Blocking Filters for Imaging X-ray Detectors: Technology Development for the International X-ray Observatory	Mark Bautz	MIT	FY2012, 4 years	X-ray	Detector
SAT2012	Phase Measurement System Development for Interferometric Gravitational Wave Detectors	William Klipstein	JPL	FY2014, 3 years	GW	Electronics
SAT2012	Demonstration of a TRL 5 Laser System for eLISA	Jordan Camp	GSFC	FY2014, 2 years	GW	Laser
SAT2013 SAT2010	Reflection Grating Modules: Alignment and Testing	Randy McEntaffer	U. of Iowa	FY2015, 2 years	X-ray	Optics
SAT2013 SAT2010	Advanced Packaging for Critical Angle X-ray Transmission Gratings	Mark Schattenburg	MIT	FY2015, 2 years	X-ray	Optics
SAT2013	Technology Development for an AC-Multiplexed Calorimeter for ATHENA	Joel Ullom	NIST	FY2015, 2 years	X-ray	Detector
SAT2013 APRA2011	Development of 0.5 Arc-second Adjustable Grazing Incidence X-ray Mirrors for the SMART-X Mission Concept	Paul Reid	SAO	FY2015, 3 years	X-ray	Optics
SAT2013 SAT2011	Affordable and Lightweight High-Resolution Astronomical X-Ray Optics	William Zhang	GSFC	FY2015, 2 years	X-ray	Optics
SAT2013	Fast Event Recognition for the ATHENA Wide Field Imager	David Burrows	PSU	FY2015, 2 years	X-ray	Detector
SAT2014 SAT2012 SAT2010	Superconducting Antenna-Coupled Detectors and Readouts for Space-Borne CMB Polarimetry	Jamie Bock	JPL	FY2016, 2 years	CMB	Detectors
SAT2014 & SAT2011	Telescope Dimensional Stability Study for a Space-based Gravitational Wave Mission	Jeffrey Livas	GSFC	FY2016, 2 years	GW	Telescope
SAT2014	High Efficiency Feedhorn-Coupled TES-based Detectors for CMB Polarization Measurements	Edward Wollack	GSFC	FY2016, 2 years	CMB	Detector
Directed 2016	Providing Enabling and Enhancing Technologies for a Demonstration Model of the Athena X-IFU	Caroline Kilbourne	GSFC	FY2016, 2 years	X-ray	Detector

Directly Deposited Optical-Blocking Filters for Imaging X-ray Detectors

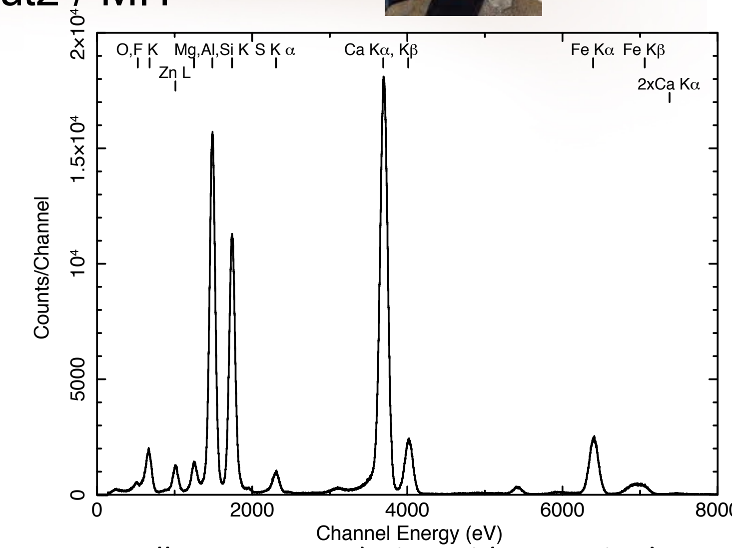
PI: Mark Bautz / MIT

Objectives and Key Challenges:

- Silicon imaging X-ray detectors require thin filters (<300 nm) to block noise/background from UV and optical light
- State-of-the-art, free-standing filters use fragile, thin substrates
- Objective: deposit blocking filter directly on CCD X-ray detector, eliminating substrate
- Challenges:
  — Deposit filter directly without compromising CCD performance
  — Deposit sufficiently thin, uniform filters

Significance of Work:

- Filter deposited on detector requires no fragile substrate
- Allows cheaper, more robust sensors (no vacuum housing!)
- Improves QE and makes larger focal planes practical



Excellent CCD Resolution with Deposited OBF

Approach:

- Exploit existing stocks of (engineering grade/flight spare) X-ray CCD detectors at MIT Lincoln Laboratory
- Screen, thin, passivate, package, and apply filters to detectors
- Filter is Al with AlO_2 cap
- Start thick (220 nm Al), get progressively thinner
- Use existing MIT facilities for X-ray characterization
- Use existing and upgraded facilities for optical characterization

Key Collaborators:

- Bautz and Kissel (MIT Kavli Institute)
- Suntharalingam, Ryu, Burke, and O'Brien (MIT Lincoln Laboratory)

Current Funded Period of Performance:

Jul 2012 – Jun 2017

Recent Accomplishments:

✓ Reduced pinhole fraction to < 1% (OD<7) for 220-nm OBF
✓ Tested devices with 70 nm and 100 nm thick Al OBF; optical blocking as expected
✓ With REXIS, developed and qualified underside coating as effective countermeasure for near-IR leakage through package
✓ Supported environmental tests of REXIS flight CCDs/OBFs

Next Milestones:

- Continue long-term stability test; no degradation in 8 months (Mar 2017)
- Complete post-environmental REXIS OBF performance test and **demonstrate TRL 6, surpassing project goals** (May 2017)

Applications:

Every X-ray imaging or grating spectroscopy mission

- Explorers (ETA, STAR-X, Arcus, etc.)
- "Probes" (AEGIS, N_XGS, AXSIO, WFXT, etc.)
- Flagship (Athena, X-ray surveyor)

TRL_{In} = 5 $TRL_{Current}$ = 5 TRL_{Target} = 6

Gravitational-Wave-Mission Phasemeter Technology Development

PI: Bill Klipstein / JPL

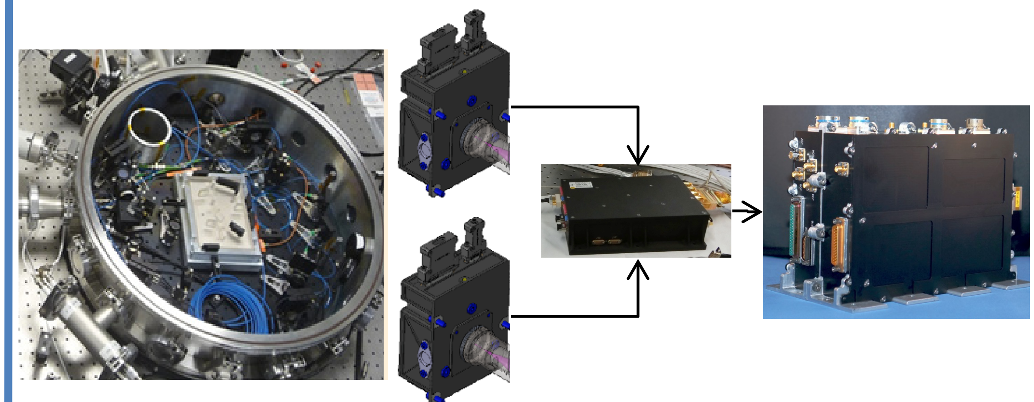
Objectives and Key Challenges:

- Advance our phase-measurement system from TRL 4 to 5 through significant system-level hardware-fidelity increase and greater fidelity of signal-test environment by adding low light levels
- Mature the TRL of phase readout with high strain sensitivity through micro-cycle/√Hz precision on a 4-16 MHz beat-note in the presence of laser frequency noise and local clock noise, already demonstrated in a lab testbed

Significance of Work:

- High-performance phase readout is an enabling technology for multi-spacecraft laser-interferometer-based missions such as LISA-like gravitational-wave missions

EM Hardware (quadrant photoreceivers, preamp, and phasemeter) infused into the LISA test-bed



Approach:

- Advance component technologies
  - Infuse compatible EM hardware from GRACE Follow-On Laser-Ranging Interferometer (LRI)
  - Demonstrate wavefront sensing with quadrant photoreceivers
- System-level testing
  - Modify interferometer test-bed to include low-light signals
  - Replace COTS components in interferometer test-bed with LRI EM hardware and demonstrate performance

Key Collaborators:

- Jeff Dickson, Brent Ware, Bob Spero, Kirk McKenzie, Andrew Sutton, and Chris Woodruff (JPL)

Current Funded Period of Performance:

Apr 2014 – Dec 2016

Recent Accomplishment:

✓ Demonstrated phase readout with micro-cycle/√Hz precision in the presence of laser frequency noise and local clock noise in an interferometer test-bed

Next Milestones:

- Incorporate quadrant photoreceivers into test-bed (Sep 2016)
- Demonstrate wavefront sensing (Sep 2016)
- Migrate additional photoreceiver algorithms from LabView phasemeter to EM (Oct 2016)
- Incorporate EM photoreceivers and signal chain (Nov 2016)
- Demonstrate tracking of low-visibility signals with EM Phasemeter (Dec 2016)
- Demonstrate test-bed performance at TRL 5 or higher (Dec 2016)

Applications:

- Inter-spacecraft laser interferometry and pm-precision interferometer readout electronics for future missions, e.g., LISA
- Other interferometry concepts (e.g., planet searches)

TRL_{In} = **4** $TRL_{Current}$ = **4** TRL_{Target} = **5**

Demonstration of a TRL-5 Laser System for LISA

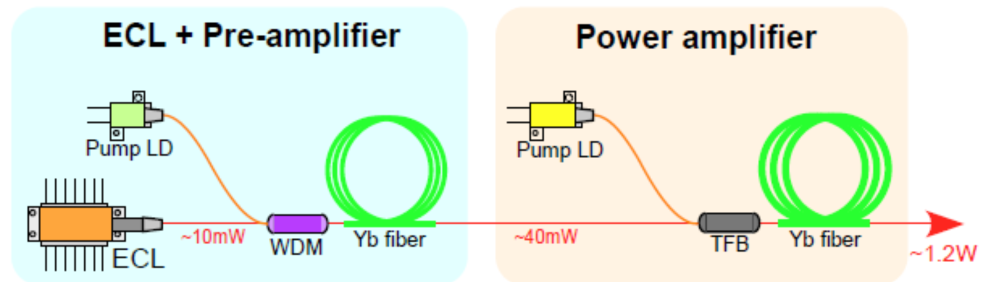
PI: Jordan Camp / GSFC

Objectives and Key Challenges:

- Develop 2.5-W light source for the LISA gravitational-wave (GW) mission using a Master Oscillator Power Amplifier design with a novel diode laser oscillator (External Cavity Laser, ECL) followed by a 2.5-W Yb fiber amplifier, providing a highly stable, compact, and reliable system
- Test the laser system for reliability, and for amplitude and frequency stability, achieving the required noise performance
- Demonstrate system TRL 5
- Develop with industrial partner (Redfern Integrated Optics, RIO) space-qualified, ultra-low-noise oscillator
- Demonstrate low-noise power amplifier with servo controls
- Noise and reliability tests of full laser system

Significance of Work:

- Required for LISA or any similar GW mission



Master Oscillator / Power Amplifier (MOPA) configuration of LISA laser, including ECL, preamp, and diode-pumped Ytterbium (Yb) fiber amplifier. All components have been tested for noise and reliability except for amplifier reliability, to be tested by fall 2016

Approach:

- Noise optimization of 1064-nm ECL (RIO)
- Reliability study of ECL
- Implementation of amplitude and frequency servo controls on full laser system, achieving RIN=10^{-4} at 10^{-3} Hz, frequency noise = 300 Hz / $\mathrm{Hz}^{1/2}$ at 10^{-2} Hz, and differential phase noise = 6×10^{-4} rad/$\mathrm{Hz}^{1/2}$ at 10^{-2} Hz

Key Collaborators:

- Kenj Numata, Mike Krainak (NASA/GSFC)
- Lew Stolpner (RIO)

Development Period:

- Apr 2014 – Sep 2016

Accomplishments:

- ✓ Fabricated world's first butterfly package layout 1064 nm ECL
- ✓ Procured long lead items: fiber splicers and coaters
- ✓ Developed and constructed 2.5-W laser amplifier
- ✓ Noise tested laser system with ECL
- ✓ Optimized noise levels of ECL optical cavity
- ✓ Tested reliability of ECL and preamp

Next Milestones:

- Amplifier reliability tests (Sep 2016)
- Full laser system monitoring (Sep 2016)

Applications:

- Laser source for LISA GW mission
- Oscillator for ground-based GW LIGO project
- Oscillator for GRACE-II mission

*TRL_{In} = **3*** *$TRL_{Current}$ = **3*** *TRL_{Target} = **5***

Reflection Grating Modules: Alignment and Testing

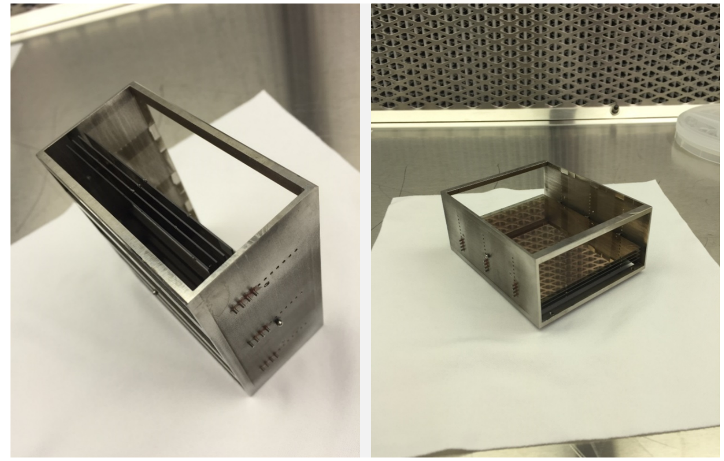
PI: Randall L. McEntaffer / PSU

Objectives and Key Challenges:

- Implement an alignment methodology specific to off-plane reflection gratings
- Populate a module with aligned gratings achieving spectral resolution > 3000 ($\lambda/\delta\lambda$) with high throughput over the 0.2-2.0-keV band
- Advance the OP-XGS technology to TRL 5

Significance of Work:

- Enables high throughput and high spectral resolving power below 2 keV, where the majority of X-ray spectral features reside
- This will be the first time that multiple off-plane gratings have been aligned at this tolerance level with associated performance testing



An aligned grating module assembly incorporating four full-format (75 mm × 96 mm × 0.5mm) off-plane diffraction gratings

Approach:

- Quantify alignment tolerances
- Formulate alignment methodology
- Implement alignment methodology
- Performance- and environmental-test an aligned module

Key Collaborators:

- Will Zhang (NASA/GSFC)
- Jessica Gaskin (NASA/MSFC)

Current Funded Period of Performance:

Jan 2015 – Dec 2016

Recent Accomplishments:

- ✓ TRL 4 vetted
- ✓ Alignment setup used to align four flight-like gratings into a high-fidelity module
- ✓ The module has been performance- and environmental-tested at the Stray Light Facility at MSFC

Next Milestone:

- Analyze and publish performance/environmental test results from MSFC (Q3-Q4 2016)

Applications:

- Large X-ray observatories
- Explorer-class missions
- Suborbital-rocket investigations

$TRL_{In} = 4$ $TRL_{Current} = 4$ $TRL_{Target} = 5$

Advanced Packaging for Critical-Angle X-ray Transmission Gratings

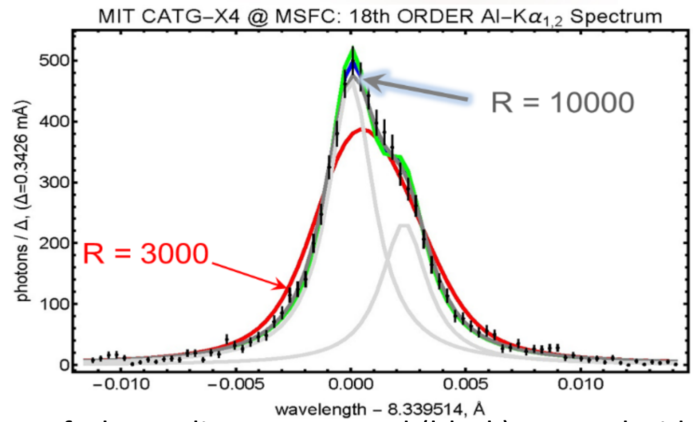
PI: Mark Schattenburg / MIT

Objectives and Key Challenges:

- Develop key technology to enable a Critical-Angle Transmission X-ray Grating Spectrometer (CATXGS), advancing to TRL 6 in preparation for proposed mid- and large-size missions over the next decade
- Develop improved grating fabrication processes
- Develop frame mounting, alignment, and assembly techniques for CAT grating arrays

Significance of Work:

- Improved diffraction efficiency and resolving power for CATXGS
- Ability to manufacture large-area, light-weight grating arrays



Spectrum of Al K$\alpha_{1,2}$ lines: measured (black), natural width (individual, light gray; combined, green); natural width with R = 3000 broadening (red); natural width with R = 10,000 broadening (dark gray).

Approach:

- Integrated wafer front/back-side fabrication process using silicon-on-insulator (SOI) wafers
- Wafer front side: CAT grating and Level 1 support structure
- Wafer back side: Level 2 support mesh structure
- CAT grating fabricated by deep reactive-ion etching (DRIE) followed by KOH polishing
- Bonded to expansion-matched metal support frame (Level 3)
- X-ray tests of prototypes at synchrotron and MSFC facility
- Environmental tests to advance TRL

Key Collaborators:

- William Zhang (GSFC)
- Steve O’Dell (MSFC)

Current Funded Period of Performance:

Jan 2015 – Dec 2016

Recent Accomplishments:

✓ Demonstrated extension of bandpass toward higher energies and/or increase in critical angle through atomic layer deposition of platinum on silicon CAT gratings

✓ Demonstrated resolving power R > 10,000 at the MSFC Stray Light Facility, using GSFC mirror and 30-mm-wide CAT gratings

Next Milestones:

- Bond gratings to frames (2017)
- Demonstrate X-ray performance of aligned gratings with prototype frame assembly after environmental tests to achieve TRL 5 (fall 2018)

Application:

- Flagship X-ray missions
- Explorer X-ray missions
- Laboratory X-ray analysis (materials science, energy research)

TRL $_{In}$ = 3 *TRL $_{Current}$ = 4* *TRL $_{Target}$ = 6*

Technology Development for an AC-Multiplexed Calorimeter for Athena

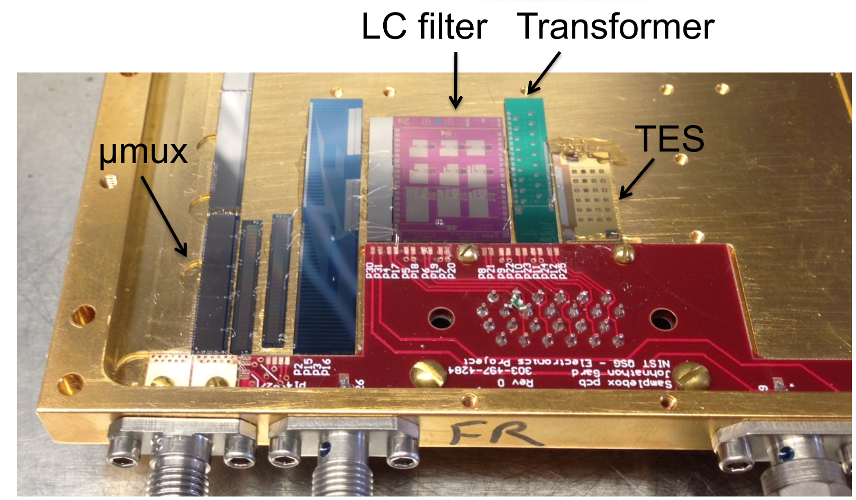
PI: Joel Ullom / NIST

Objectives and Key Challenges:

- Increase TRL of AC-biased Transition-Edge Sensor (TES) X-ray microcalorimeters from 3 to 4
- To achieve this, demonstrate that AC-biased TESs can meet the anticipated performance requirements of ESA's Athena mission, in particular, that AC-biased TESs can routinely achieve energy resolutions of 2.5 eV or better at 6 keV
- The key challenge is that, so far, TESs under AC bias do not have as good energy resolution as under DC bias

Significance of Work:

- AC-biased TESs and Frequency Division Multiplexing (FDM) are the baseline readout architecture for Athena; the performance of this approach strongly impacts mission design and success



Sample box for readout of AC-biased TESs using open-loop microwave SQUIDs

Approach:

- Study the behavior of single GSFC TESs under AC bias
- In one experiment, maximize the use of readout components from the European Athena team
- In a second experiment, separate the effects of the readout system from the TES by using a novel, open-loop readout architecture based on microwave SQUID amplifiers
- Study interactions among small numbers of AC-biased TES devices

Key Collaborators:

- Caroline Kilbourne, Simon Bandler, and Richard Kelley (GSFC)
- Kent Irwin (Stanford University)

Current Funded Period of Performance:

FY 2015 – FY 2016

Recent Accomplishments:

✓ Completed two new complementary measurement platforms for characterizing AC-biased TESs

✓ Successfully demonstrated microwave-SQUID-based readout capable of measuring TESs at a sample rate of 8 MHz

✓ Demonstrated 2.9 eV energy resolution for AC-biased TESs @ 6keV

Next Milestones:

- Characterize AC-biased TESs with both FDM and microwave SQUID amplifiers (Q4 FY16)
- Study interactions among AC-biased TESs (Q4 FY16)

Applications:

- Athena and future X-ray missions based on TES microcalorimeters

TRL_{In} = 3 $TRL_{Current}$ = 3 TRL_{Target} = 4

Development of 0.5-Arcsecond Adjustable Grazing-Incidence X-ray Mirrors for the SMART-X Mission Concept

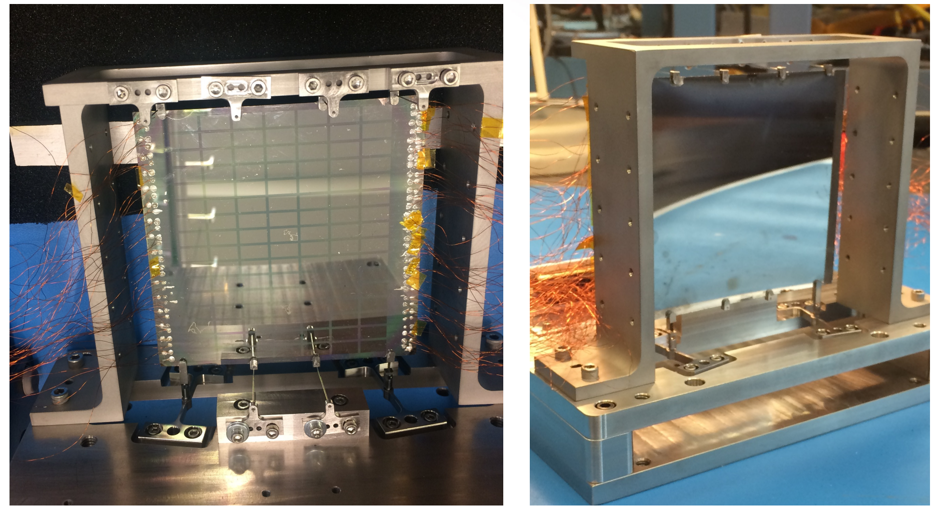
PI: Paul Reid / SAO

Objectives and Key Challenges:

- Develop an alignment and mounting scheme consistent with a large-area, high-resolution X-ray telescope (> 2m^2 and 0.5”) that accommodates many (~100) closely packed mirror segments, aligned to 0.25” = Chandra alignment (mounting distortions <1 µm P/V (correctable with adjusters)
- Approach must allow calibration of mirror surface figure as each segment is mounted so that figure can be corrected before next segment is aligned
- Incorporate developments in high-connection-density flexible cabling and row-column addressing to minimize and simplify electrical connections for mirror-adjuster command and control

Significance of Work:

- Enables adjustable optics to correct mounting-induced distortion and on-orbit thermal changes with LCD-display electrical simplicity



Single shell mounting concept with a mounted adjustable mirror

Approach:

- Investigate Anisotropic Conductive Films (ACFs) for high connection density (up to 100 contacts/mm)
- Develop ZnO thin film transistor over-layer with insulating top layer for row-column addressing and ease of electrical-contact routing
- Through structural and thermal analysis and design, incorporate and extend alignment and mounting approach being developed for APRA TRL4 X-ray test

Key Collaborators:

- Susan Trolier-McKinstry, Tom Jackson, and Tianning Liu (PSU)
- Brian Ramsey and Steve O’Dell (MSFC)

Current Funded Period of Performance:

Proposed Jan 2015 – Dec 2016
Funding available Apr 2015, so plan Apr 2015 – Mar 2017

Recent Accomplishments:

- ✓ Generated preliminary thermal control system requirements
- ✓ Demonstrated ZnO TFT row-column addressing on flat test mirror
- ✓ Demonstrated ACF connections on flat test mirror

Next Milestones:

- High-fidelity deterministic figure control test (Nov 2016)
- Development of ACF connectivity on conical optics (Nov 2016)
- X-ray-test mounted, corrected, and aligned mirror pair (May 2017)

Application:

- X-ray Surveyor (formerly SMART-X) mission concept

TRL_{In} = 3 $TRL_{Current}$ = 3 TRL_{Target} = 4

Next-Generation X-ray Optics: High Angular Resolution, High Throughput, and Low Cost

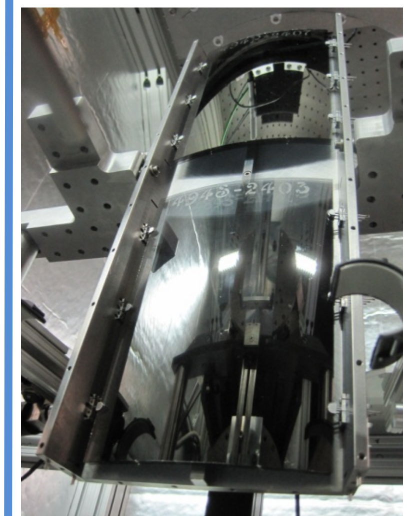
PI: William W. Zhang / GSFC

Objectives and Key Challenges:

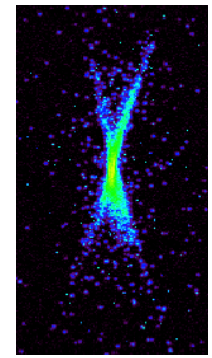
- Develop lightweight X-ray-mirror technology achieving better than 10-arcsec HPD angular resolution while minimizing cost and schedule; advance to TRL 5 to enable missions planned for 2010s and 2020s
- Prepare ways to achieve significantly better than 10-arcsec resolution while keeping the mass and cost at similar levels
- Fabrication and metrology of mirror segments
- Coating mirror segments with 20 nm of iridium w/o distortion
- Alignment and bonding of mirror segments

Significance of Work:

- Enables major X-ray observatories such as ESA's Athena and NASA's Astrophysics Roadmap X-ray Surveyor



Technology Development Module containing three pairs of parabolic-hyperbolic mirror segments



X-ray image with 8-arcsec HPD

Approach:

- Precision glass slumping to make mirror substrates
- Use magnetron sputter or atomic layer deposition to maximize X-ray reflectance
- Use interferometer, null lens, and interferometric microscope to conduct measurements
- Use Hartmann tests to align mirror segments
- Develop precision epoxy-bonding techniques

Key Collaborators:

- Michael Biskach, Kai-Wing Chan, Ryan McClelland, and Timo Saha (GSFC)
- Stephen O'Dell (MSFC)

Current Funded Period of Performance:

Oct 2014 – Sep 2016

Recent Accomplishments:

✓ Slumped mirror substrates achieving better than 10-arcsec HPD
✓ Coated mirror substrates with 15 nm of iridium without distortion
✓ Repeatedly co-aligned and bonded multiple mirror pairs, achieving 8-arcsec HPD X-ray images

Next Milestone:

- Refine mirror bonding process to fully realize mirror segment potential of 6.5-arcsec HPD (Dec 2016)

Applications:

- Flagship and probe-class X-ray missions
- Explorer-type X-ray missions
- Medical research and diagnosis

$TRL_{In} = 3$ $TRL_{PI\text{-}Asserted} = 5$ $TRL_{Target} = 6$

Fast Event Recognition for the Athena Wide-Field Imager

PI: David Burrows / PSU

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NASA

PCOS Physics of the Cosmos

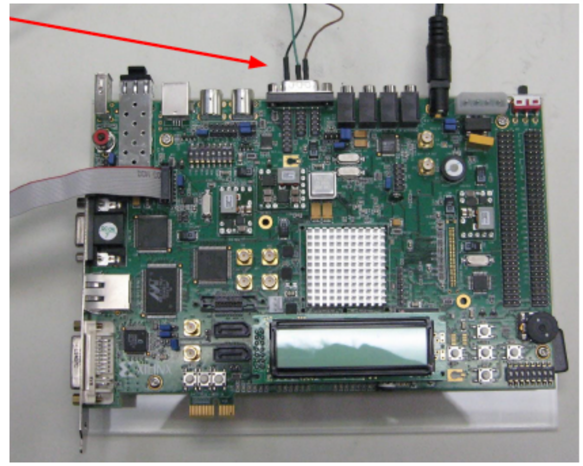
COR Cosmic Origins

Objectives and Key Challenges:

- High-speed event recognition and data compression

Significance of Work:

- Required for several proposed X-ray imagers, including Athena WFI (ESA L2), JANUS XCAT (EX), XTiDE XCAT (SMEX), Arcus (MIDEX), X-ray Surveyor (Astrophysics Roadmap)



Virtex-5 OpenSPARC Evaluation Platform, designed to be a flexible development board for testing high-speed Virtex-5-class FPGAs

Approach:

- FPGA coding/simulation/testing
- Testing with fixed patterns up to 1GBps
- Testing with real X-ray data up to 1GBps

Key Collaborators:

- Dr. Karl Reichard and Eli Hughes (PSU/ARL)
- Dr. Abe Falcone and Dr. Tyler Anderson (PSU/ECOS)
- Dr. Mark Bautz (MIT)
- Dr. Ralph Kraft (SAO)

Current Funded Period of Performance:

Jan 2015 – Dec 2016

Recent Accomplishments:

- ✓ Completion of Line Processor testing
- ✓ Design of full single-channel ERP
- ✓ Schematic design and PC layout of single-channel ERP board

Next Milestones:

- Fabrication and test single-channel ERP board (Aug 2016)
- TRL review (Nov 2016)

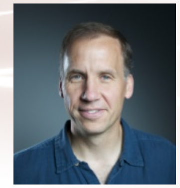
Applications:

- Athena WFI (ESA L2)
- JANUS XCAT (EX)
- XTiDE XCAT (SMEX)
- Arcus (MIDEX)
- X-ray Surveyor (Astrophysics Roadmap)

$TRL_{In} = 3$ $TRL_{Current} = 3$ $TRL_{Target} = 4$

Planar Antenna-Coupled Superconducting Detectors for CMB Polarimetry

PI: James Bock / JPL, Caltech



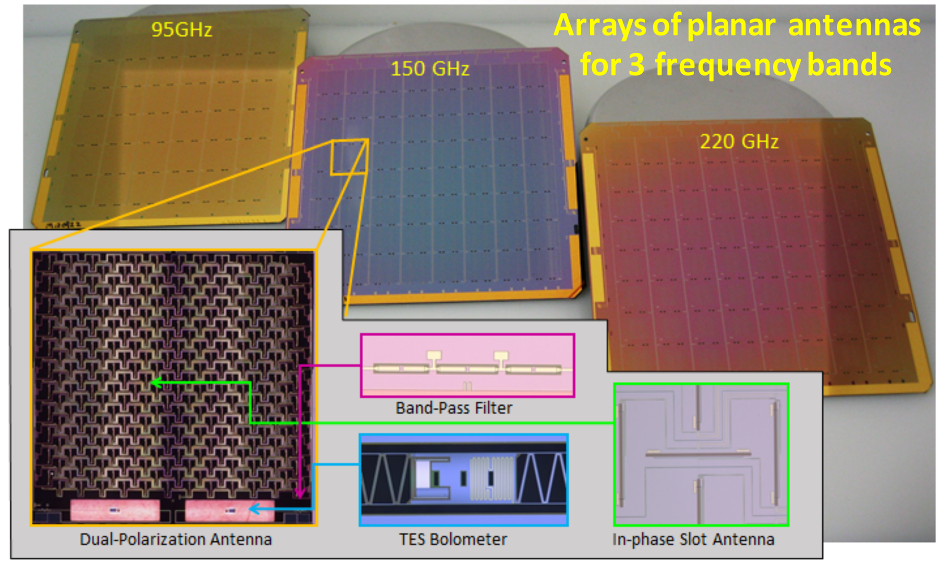
Objectives and Key Challenges:

Advance antenna-coupled superconducting detector technologies for space requirements:

- RF propagation properties
- Beam control and polarized matching
- Extended-frequency antennas
- Detector stability and cosmic-ray response
- Readout-noise stability
- Large-format, modular, focal-plane units

Significance of Work:

- Antenna designs for all bands required by the Inflation Probe
- Detector sensitivity, stability, and minimized particle susceptibility appropriate for space-borne observations



Approach:

- Planar antennas for entirely lithographed fabrication with no coupling optics
- Detectors provide photon-limited sensitivities in space
- Antennas provide excellent polarization and beam-matching properties
- Modular focal-plane unit for large focal-plane arrays

Key Collaborators:

- Koko Megerian, Hien Nguyen, Roger O'Brient, Anthony Turner, and Alexis Weber (JPL)
- Jon Hunacek, Howard Hui, Sinan Kefeli, and Bryan Steinbach (Caltech)
- Jeff Filippini (UIUC)

Current Funded Period of Performance:

Jan 2016 – Dec 2017

Recent Accomplishments:

- ✓ BICEP3 deploys 20 focal-plane modules at 95 GHz
- ✓ 40 GHz antennas demonstrated
- ✓ 270 GHz and broadband antennas fabricated, in test
- ✓ Ti resistivity and dielectric uniformity characterized on 6" wafers

Next Milestones:

- Results from 270-GHz antenna test (Jul 2016)
- Results from broad-band antenna test (Jul 2016)
- First cryo run of RF testbed (Aug 2016)
- Develop 6" module design (Sep 2016)

Applications:

- NASA Inflation Probe mission
- Explorer and international CMB missions
- Technology commonalities with Far-IR and X-Ray missions

TRL_{In} = **3-4** $TRL_{PI\text{-}Asserted}$ = **3-6** TRL_{Target} = **4-6**

Telescopes for Space-Based Gravitational-Wave Observatories

PI: Jeff Livas / GSFC

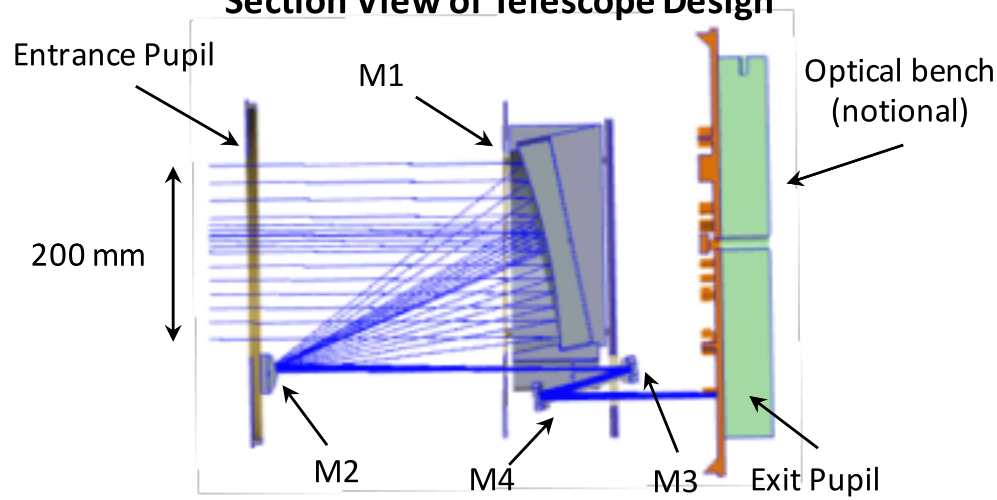
Objectives and Key Challenges:

- Design, fabricate, and test a lightweight eLISA telescope design in a flight-like environment and demonstrate the ability to satisfy mission requirements for low scattered light and high dimensional stability in time for selection for the eLISA L3 Mission Opportunity
- Key Challenge 1: dimensional stability
- Key Challenge 2: stray-light performance

Significance of Work:

- First demonstration of a validated scattered-light model combined with a previous demonstration of dimensional stability will provide a firm basis for a realistic engineering model design for a flight-qualifiable telescope
- Potential technology contribution to ESA L3 Cosmic Visions

Section View of Telescope Design



Approach:

- Use requirements developed for existing telescope
- Modify based on experience
- Merge a high-thermal-conductivity material in a simple symmetric mechanical configuration with a low-scatter optical design
- Fabricate and test for compliance with specifications

Key Collaborators:

- J. Howard, G. West, P. Blake, L. Seals, R. Shiri, J. Ward (NASA/GSFC)
- Prof. Guido Mueller (University of Florida)

Currently Funded Period of Performance:

Oct 2015 – Sep 2017

Recent Accomplishments:

✓ Optical design optimized and toleranced
✓ High level mechanical model developed
✓ Procurement paperwork submitted

Key Milestones:

- Design preparation/initiate purchase (May 2016)
- Award contract (Sep 2016)
- Telescope delivery (Dec 2017)
- Demonstrate low scatter performance (Jul 2017)
- Demonstrate optical path-length stability (Sep 2018)

Applications:

- Flagship gravitational wave missions (eLISA)
- Laser ranging and/or communications
- precision metrology applications

$TRL_{In} = 3$ $TRL_{Current} = 3$ $TRL_{Target} = 4$

High-Efficiency Feedhorn-Coupled TES-based Detectors for CMB Polarization Measurements

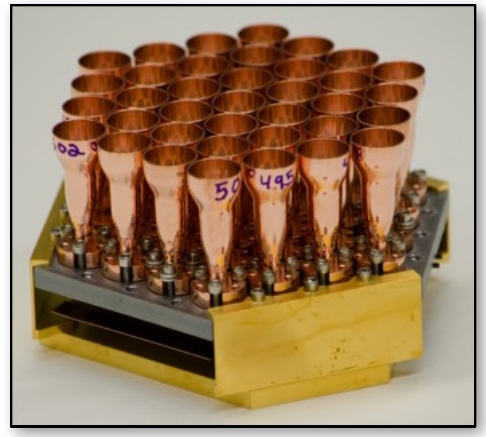
PI: Edward J. Wollack / GSFC

Objectives and Key Challenges:

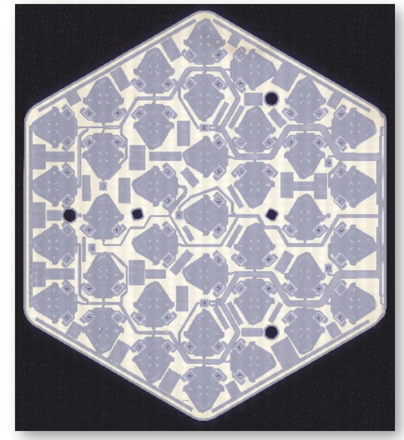
- Development of focal planes for characterization of CMB polarization with the following detector properties:
  — Background-limited millimeter-wave polarimetric sensor with high coupling efficiency and systematic error control
  — Inherently broadband design, scalable to large-format arrays over multiple frequencies of astrophysical interest

Significance of Work:

- Sub-orbital and space-borne operation of detectors, including:
  — Improved rejection of stray light by detector architecture
  — Improved broadband performance and coupling efficiency
  — Mitigation of space environmental concerns (surface/deep dielectric charging and cosmic rays)



90 GHz Sensor Module



Detector Wafer

Approach:

- The effort is focused around 3 fabrication runs to integrate the new technologies into the detector architectures. Specifically, improved:
  — Stray light mitigation and package thermalization
  — Implementation of air-bridge crossovers and ground-plane contacts for large-bandwidth/low-loss signal routing at higher frequencies

Key Collaborators:

- K. Denis, K. U-Yen, and S.H. Moseley (GSFC)
- K. Rostem (GSFC/JHU)
- D. Chuss (Villanova)
- T. Marriage and C. Bennett (JHU)

Current Funded Period of Performance:

Jan 2016 – Dec 2017

Recent Accomplishments:

✓ Funding received; test and efforts initiated
✓ Air bridge prototype devices fabricated
✓ Backshort assembly vias and groundplane contacts demonstrated and incorporated in W-band Wafers

Next Milestones:

- W-band package design validation (Jul 2016)
- Test equipment procurement (Aug 2016)
- Device run #1 (Aug 2016)
- W-band Wafer validation (Sep 2016)

Application:

- CMB Polarimetry, suborbital

TRL $_{In}$ = 3   *TRL $_{Current}$ = 3*   *TRL $_{Target}$ = 6*

Providing Enabling and Enhancing Technologies for a Demonstration Model of the Athena X-IFU

PI: Caroline Kilbourne / GSFC

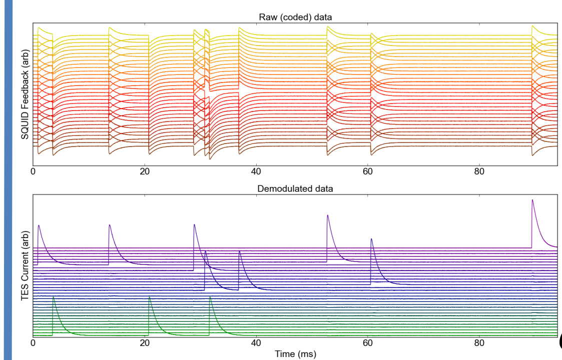
Objectives and Key Challenges:

- Develop large-format arrays of X-ray microcalorimeters and their readout for ESA's Athena X-IFU
- Support European-led primary technology demonstrations using GSFC arrays read out with frequency domain multiplexing (FDM)
- Advance TRL of time/code-division multiplexer (TDM/CDM) to maintain a viable back-up readout scheme

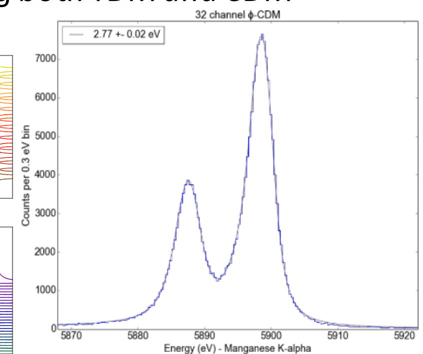
Significance of Work:

- This solid demonstration of core technologies coupled with demonstrations of targeted enhancements will enable the best possible instrument for Athena
- This development enabled NASA participation in the Athena mission

Reaching multiplexer speed and noise goals enabled breakthrough 32-row readout demonstrations using both TDM and CDM



Example raw and demultiplexed TES pulses from CDM demonstration



Combined spectrum from 32-row-CDM demonstration shows 2.77±0.02 eV resolution (FWHM)

Approach:

- Develop large-scale testing infrastructure for Athena technology demonstrations and kilo-pixel array characterization
- Optimize SQUID TDM/CDM components and electronics
- Integrate full Athena-scale TES arrays (Mo/Au TES with Au/Bi absorbers) with optimized multiplexed readout
- Provide arrays for European-led technology demonstrations using FDM
- Develop fabrication techniques for mission-enhancing 'hybrid' arrays

Key Collaborators:

- J. Adams, S. Bandler, R. Kelley, R.S. Porter, S. Smith, and J. Chervenak (GSFC)
- J. Ullom, W. B. Doriese, and C. Reintsema (NIST)
- K. Irwin (Stanford University)

Current Funded Period of Performance:

Oct 2015 – Sep 2017

Recent Accomplishment:

✓ Multiplexed 32 rows in single column with an average resolution at 6 keV of 2.55±0.01 eV using TDM and 2.77±0.02 eV using CDM

Next Milestones:

- Complete 3-column × 32-row TDM demonstration of 32 × 32 array with better than 3 eV resolution at 6 keV (Sep 2016)
- Provide uniform 32 × 32 array for Athena demonstration model and assist with 2-column × 40-row FDM technology demonstration (also requires < 3 eV resolution at 6 keV) (early 2017)

Applications:

- Contribution to the Athena mission's X-IFU instrument
- Other potential missions needing high-resolution imaging X-ray spectroscopy

$TRL_{In} = 4$ $TRL_{Current} = 4$ $TRL_{Target} = 5$